
# EUV mask imaging system based on the scanning reflective microscopy

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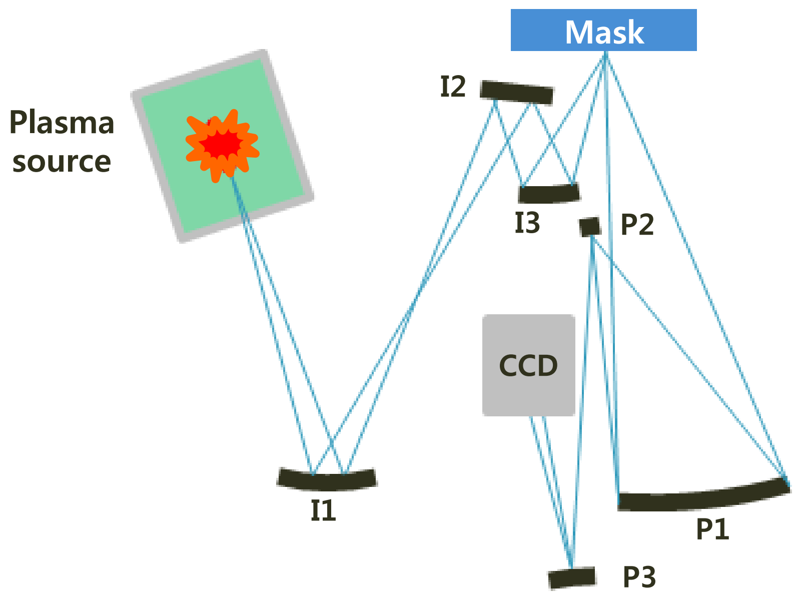
# Introduction

- In fabricating EUV mask, the printability review of the phase defects is a necessary step and it's possible only by an actinic imaging tool.
- Previously a timing gap was expected between the HVM scanner and the commercialized mask imaging tool.
- A bridge tool was developed to fill the gap based on the scanning reflective microscopy using the high-harmonic EUV source and the zone plate optics.

# Why zone plate?

- The full field imaging system with a plasma source and mirror optics is too expensive and needs a long lead time for a bridge tool purpose.

➔ The zone plate optics was considered to be an alternative option.



# Why high harmonic EUV source?

- In order to use a zone plate for full field imaging an EUV source with extremely narrow spectral bandwidth is needed.
- The synchrotron beam filtered by a monochrometer satisfies the spectral bandwidth spec., but for the manu-facturing purposes a stand-alone source is required.

➔ Among the available stand-alone EUV sources high harmonic has the most narrow spectral bandwidth.

# Why scanning?

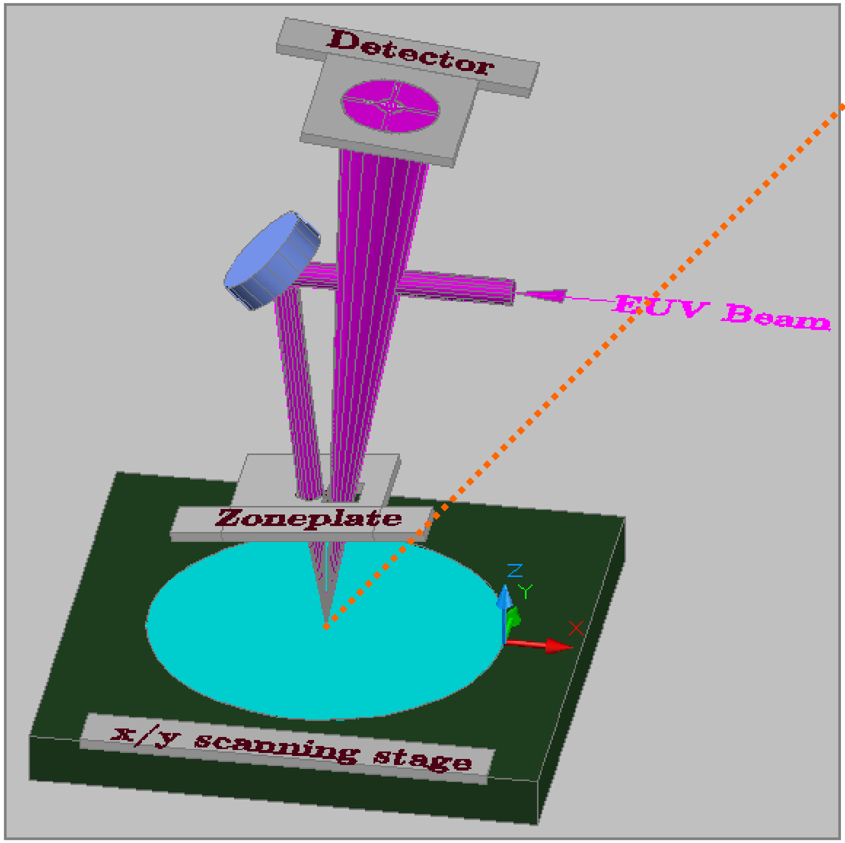
- The high harmonic EUV source is both monochromatic and stand-alone, but the spectral bandwidth is too large to be used for a full field imaging and the power is too small to be filtered by a monochrometer.

→ But in the scanning-type imaging system using on-axis focused beam, the off-axis aberration can be mitigated and consequently the spectral bandwidth requirement can be reduced significantly.

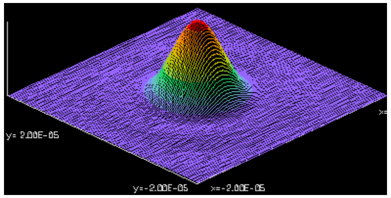
⇨ **Scanning EUV reflective microscopy**

# Scanning EUV reflective microscopy(SERM)

## Scanning EUV Reflection Microscopy(SERM)

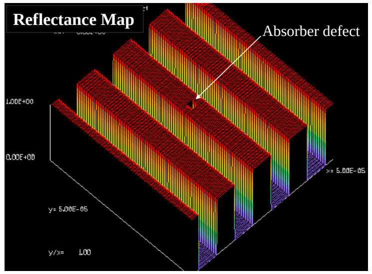



"US8335038, by *Dong-Gun Lee et al*"

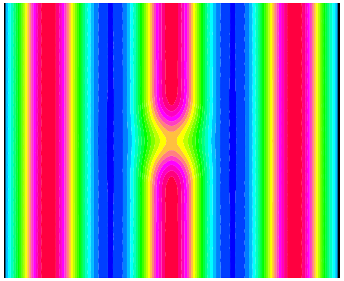


Focused beam spot
(PSF of scanner)

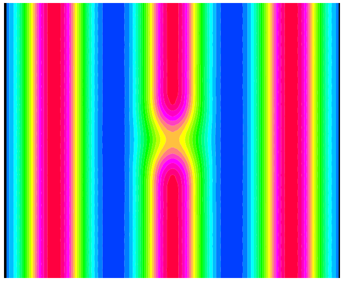
⊗ Scanning(convolution)




Mask pattern with
a phase defect



by SERM

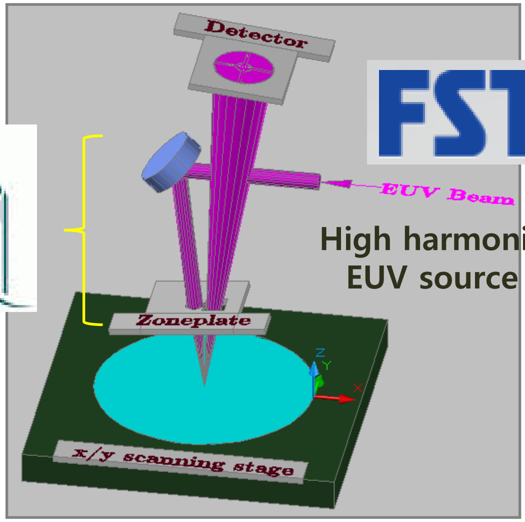


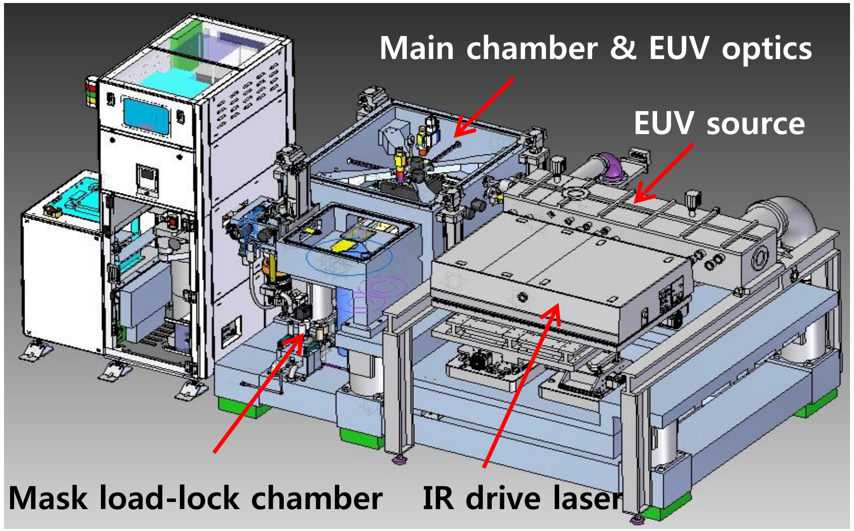
by Scanner

# Outline of the tool development

- The zone plate optics was designed and fabricated by LBNL.
- The high harmonic source was developed by Samsung and FST using COHERENT Ti:Sapphire femtosecond laser($\lambda$ = 800nm, pulse width= 46fs) and the whole system was integrated by Samsung.

Zone plate
Optics package



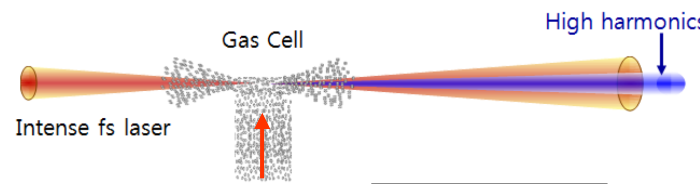
# Configuration of the high harmonic source

**Ti:Sapphire femtosecond drive laser($\lambda$=800nm, 46fs)**

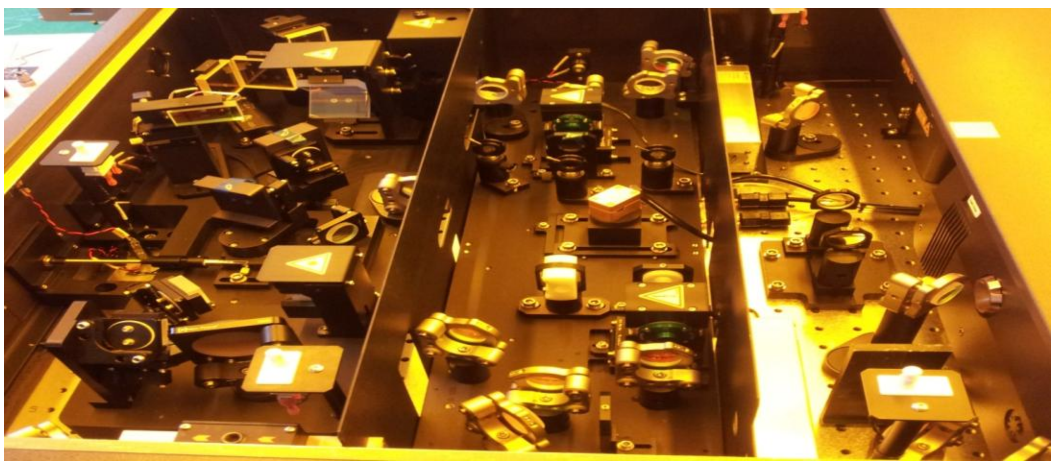
Seed Laser → Stretcher → Amplifier → Compressor

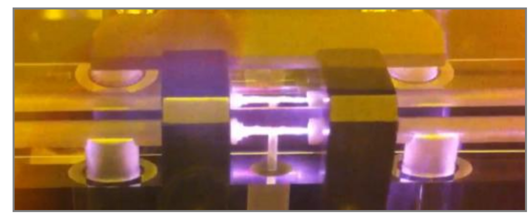
in Air

**High Harmonic Generation**




In Vacuum





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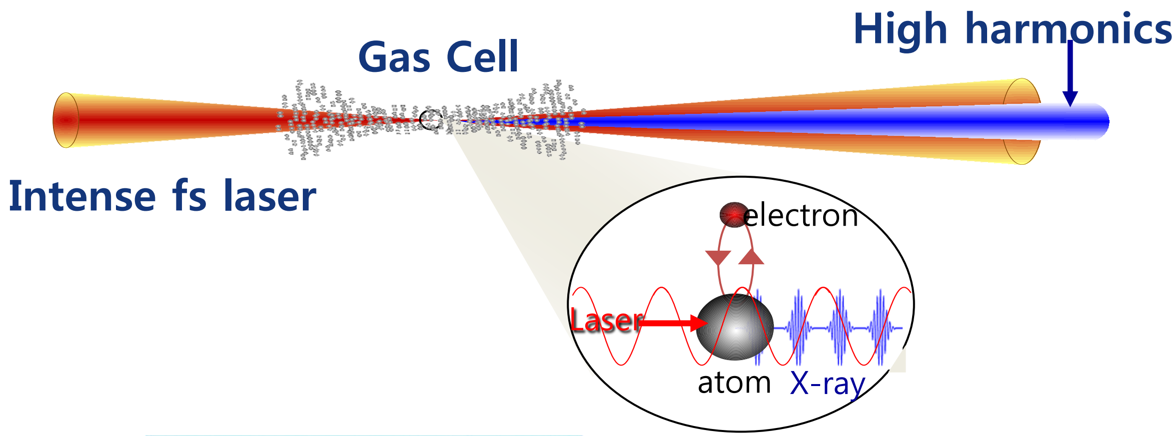
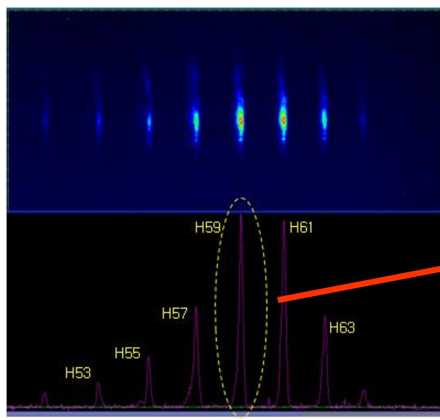
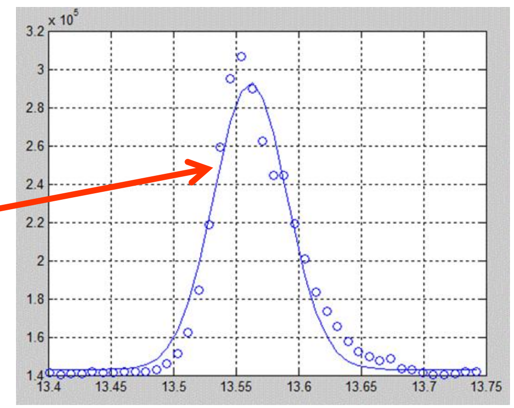
# High harmonic EUV photon generation



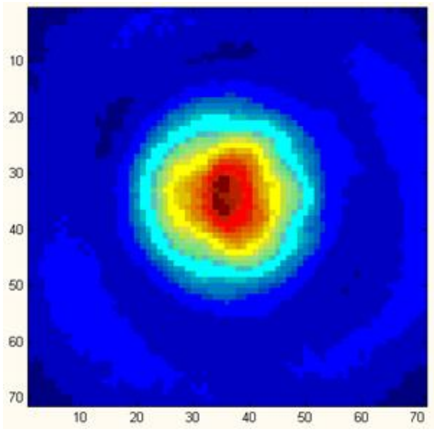



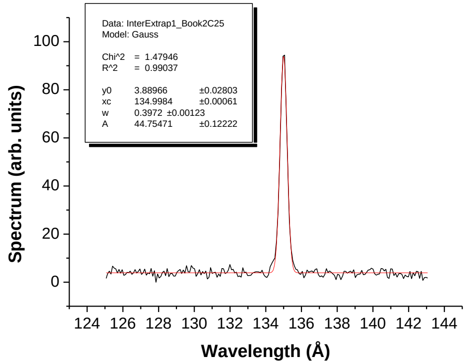

- By the highly intense($10^{14}$ ~ $10^{15}$ W/cm$^2$) IR femtosecond laser electrons are ionized, accelerated coherently, and recombined to generate the EUV light(59-th harmonic).

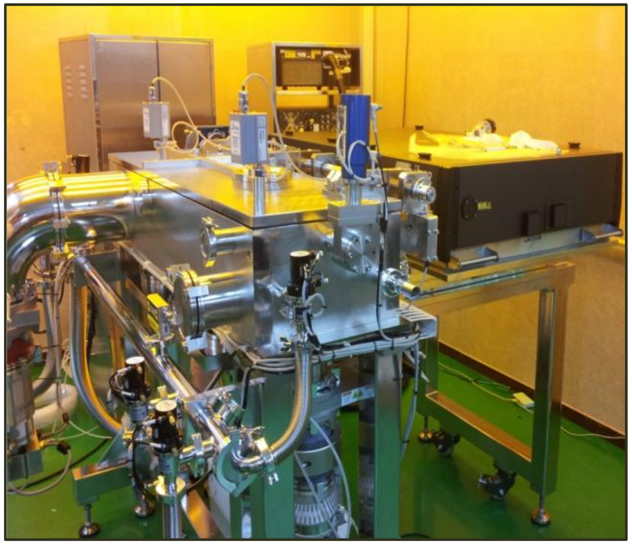
# Characteristics of the high harmonic source

EUV Power = 23.7nW

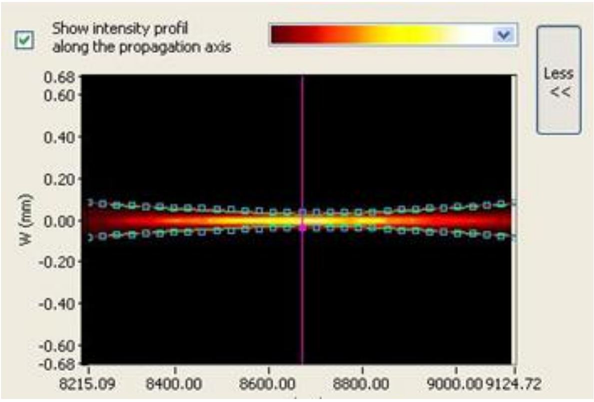


Bandwidth($\Delta\lambda/\lambda$) = 1/280

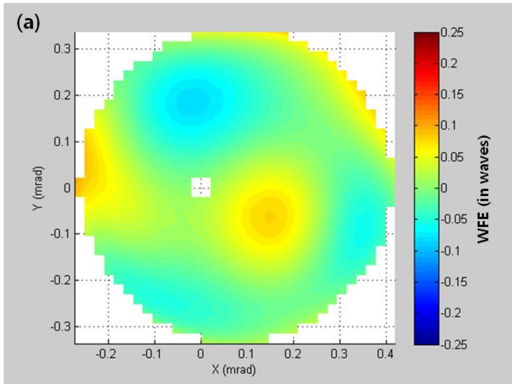


Divergence = 0.195mrad




Wavefront error = $\lambda$/67



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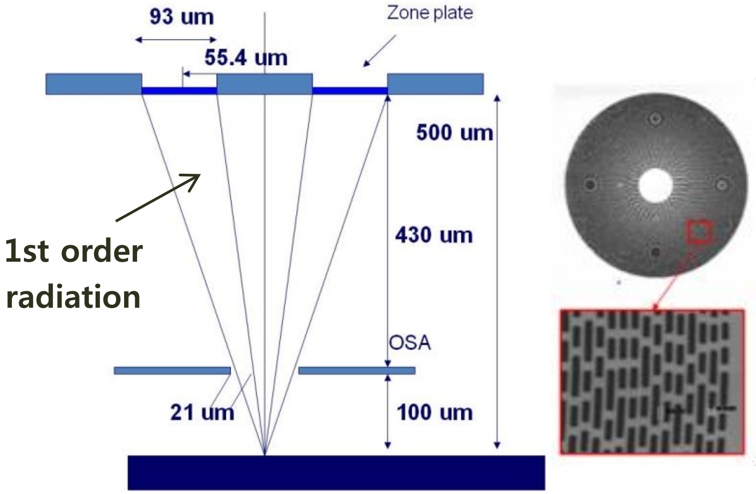
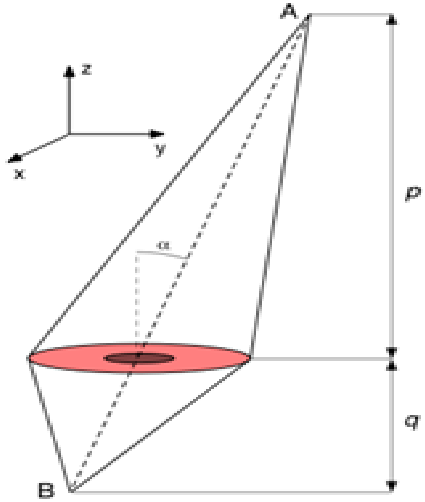
# Zone plate optics

- A free-standing elliptical zone plate with NA = 0.35(4X) and f=533μm was fabricated.
- All diffraction order radiations other than the 1st order are blocked by the order sorting aperture(OSA) to enhance the contrast.

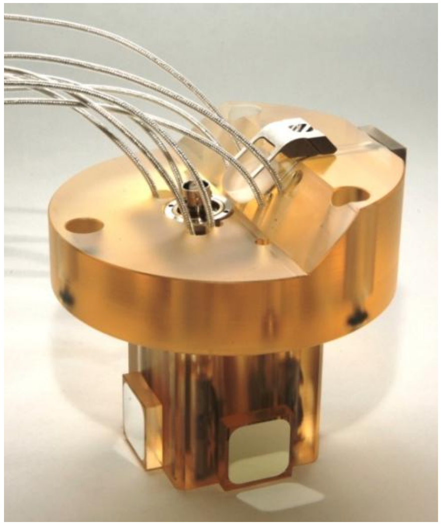
**Zone plate optics with an OSA**




**Elliptical zone plate with 6° CRA**




**Optics package**



# Characteristics of the zone plate

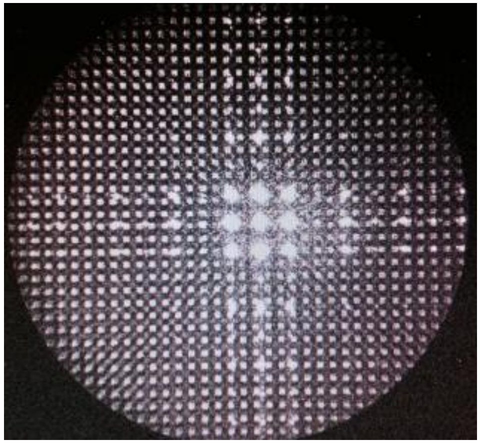
- The wavefront error of the zone plate: **λ/20**

  (illuminated by the high harmonic source and measured by the 2D grating shear Interferometer)

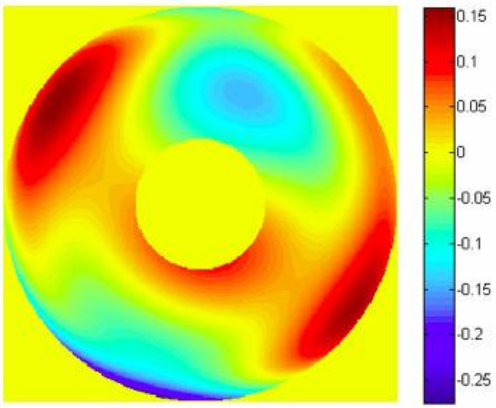
- Focused beam spot reconstructed from the wavefront: **84nm**(FWHM)

  ➔ diffraction limited

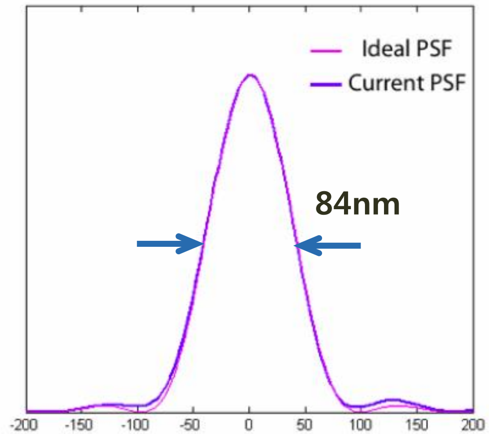
**2D grating shear Interferogram**



**Wavefront error**

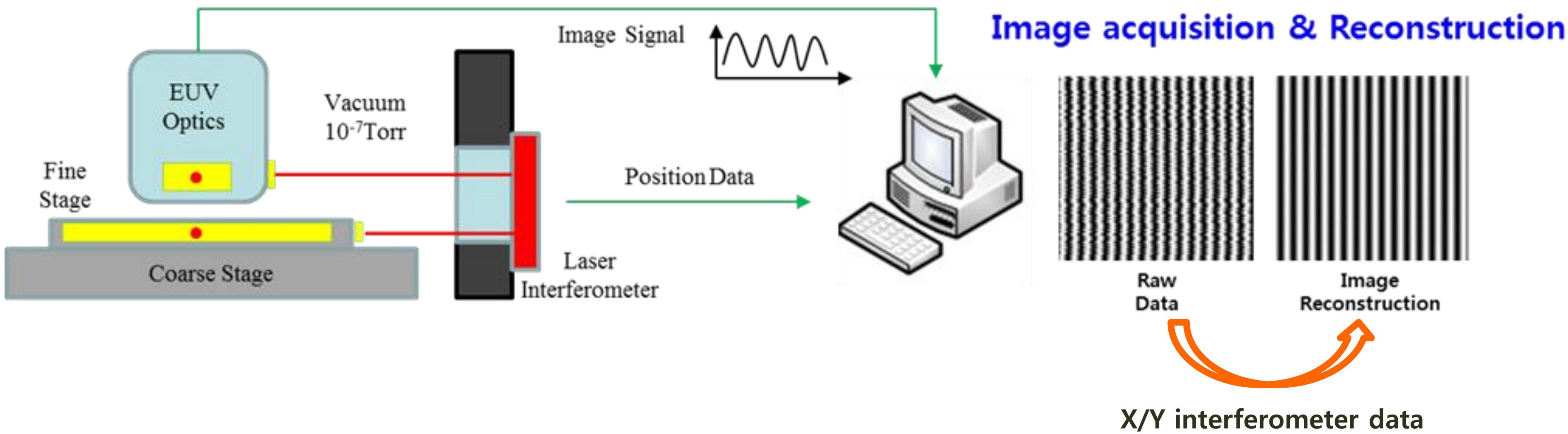



**Focused beam spot**



# Scanning stage system

- Hybrid scanning stage is applied to construct an aerial image from the focused beam spot.
- The position of the stage at each image acquisition point is measured by an interferometer and used in the image reconstruction.





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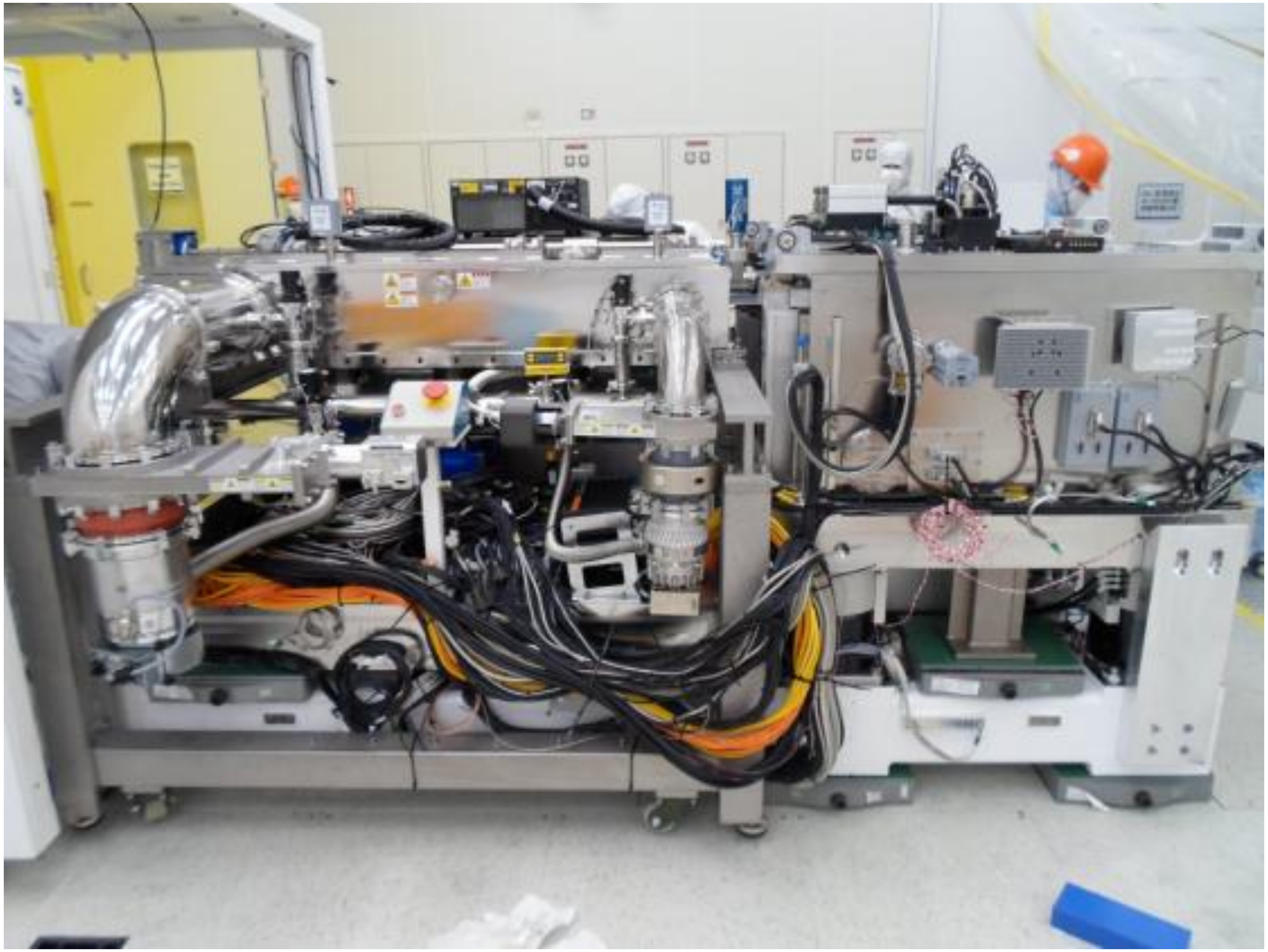
# EUV mask imaging system





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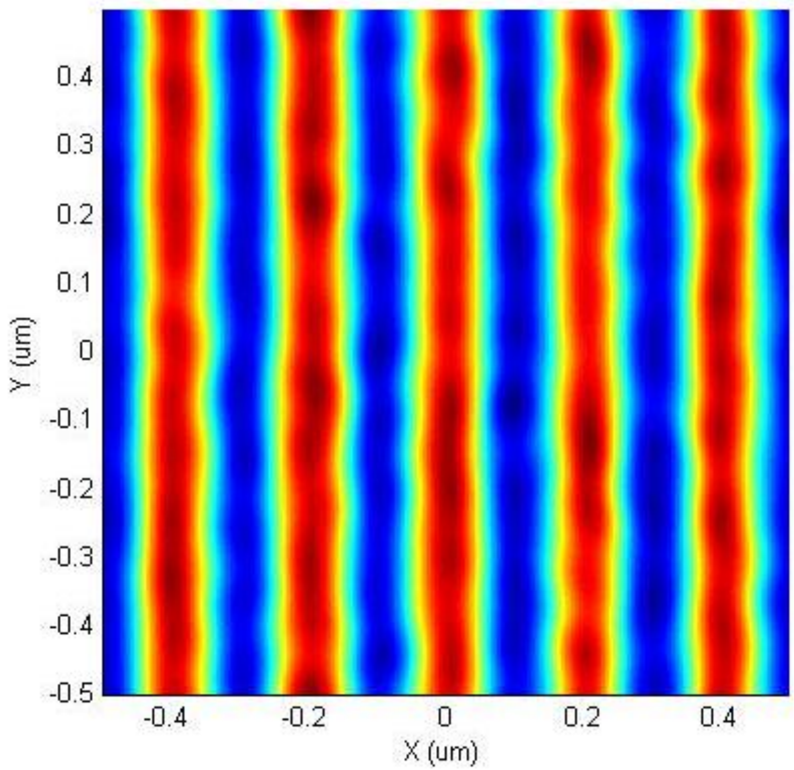
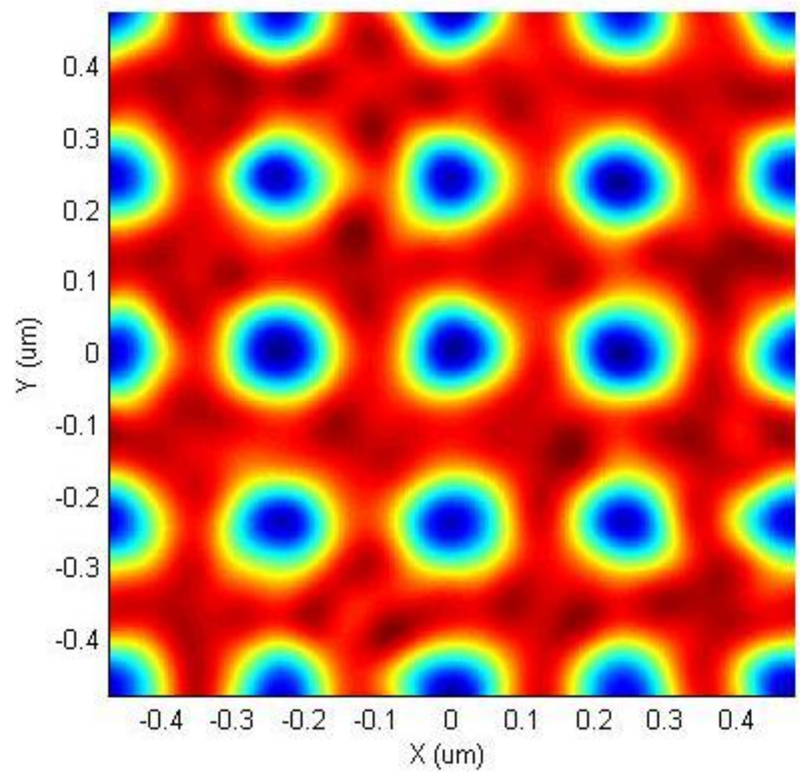
# Results: Pattern image

25nm HP(1X) L/S pattern



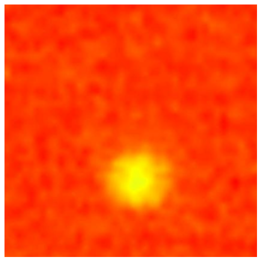
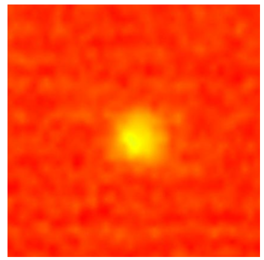
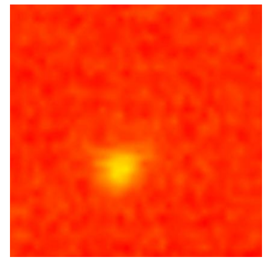
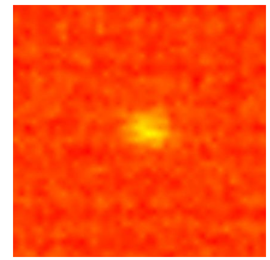
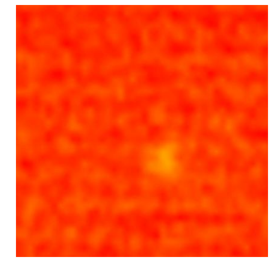

30nm HP(1X) C/H pattern



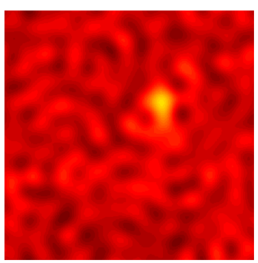
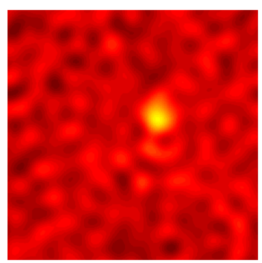
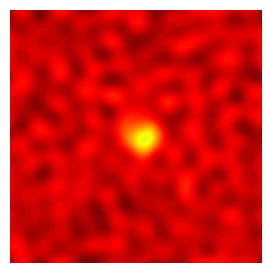
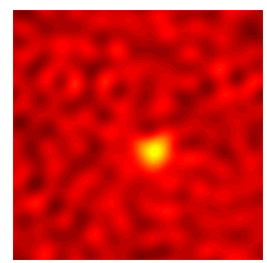
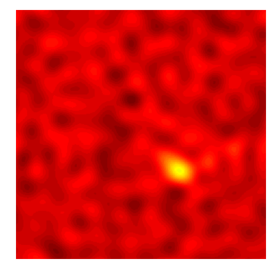

✓The major sources of the LWR are the low source power(shot noise), the mask LWR, and presumably mask surface roughness.

# Results: Phase defect images

- **Phase defect imaging sensitivity(programmed pit defect)**

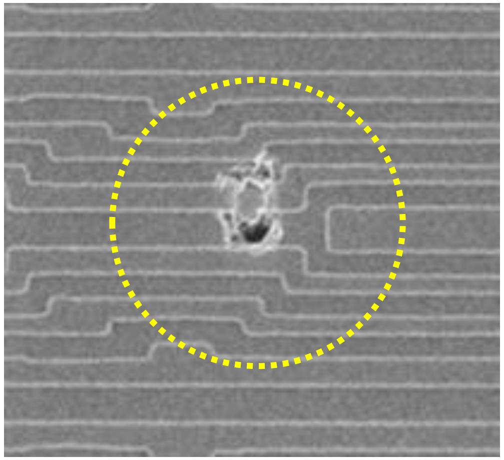
| Defect size (SEVD) | 58nm | 47nm | 37nm | 26nm | 21nm |
|---|---|---|---|---|---|
| Defect image |  |  |  |  |  |

- **Focus behavior of the phase defect(28nm-SEVD native bump defect)**

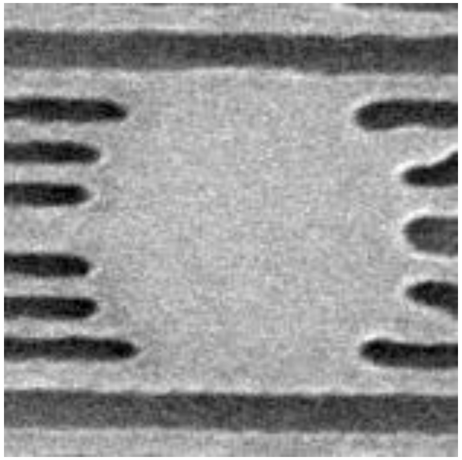
| Defocus | -1.3μm | -0.7μm | 0μm | 0.7μm | 1.3μm |
|---|---|---|---|---|---|
| Defect image |  |  |  |  |  |

# Results: Phase defect in a patterned mask

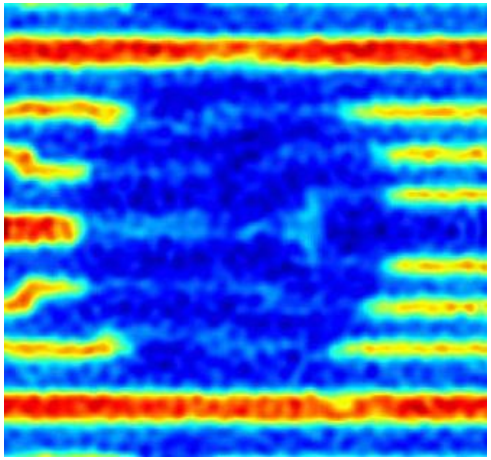
Mask SEM Image



Wafer SEM Image



Mask actinic Image



✓ **Phase defect printability on a wafer is reproduced successfully in the actinic image by this tool.**

# Application

- This tool can be used for
  - ✓ Review of phase defect printability for both patterned mask and ML blank
  - ✓ CD verification after repair of both pattern and phase defects
  - ✓ Studies on the surface roughness effect etc…
- Once commercial EUV mask imaging tool is installed for HVM, this tool can be upgraded to be a high-NA system, which is possible by simply changing the zone plate and the bending mirror.

# Summary

- Using the concept of the scanning EUV reflective microscopy an EUV mask aerial imaging system was developed.
- An aberration-free(< $\lambda$/67) high harmonic EUV source was developed using a femtosecond IR laser and a gas cell.
- A free-standing elliptic zone plate optics was developed and a diffraction-free beam spot was obtained.
- Reviewing capability of the phase defects less than SEVD-21nm were confirmed and the defect printability on the wafer pattern is reproduced successfully.
- This tool will be used for reviewing phase defect printability and upgraded for high-NA EUV studies.



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# Acknowledgement

I'd like to thank Prof. David Attwood who encouraged me to apply the high harmonic EUV source in developing EUV mask imaging system.